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ABSTRACT

This paper discusses the role of high school chemistry teachers' beliefs in implementing computer visualization software to teach atomic and molecular structure from a quantum mechanical perspective. The informants in this study were four high school chemistry teachers with comparable academic and professional backgrounds. These teachers received training on the use of software applications and the underlying scientific concepts, expressed commitment to using the software with their classes, and taught students at the same academic level. All of the participants used the software to teach concepts related to atomic and molecular structure. Their instructional approaches ranged from superficial fact-based activities to in-depth student investigations and presentations. Evidence suggests that the teachers' beliefs and personal goals shaped their decisions on how to use the software. Beliefs related to the teachers' views about how students learn and their own roles as teachers had the greatest influence on pedagogical decisions. This paper describes the instructional strategies and the implied and stated rationales of participating teachers, and develops a theory of a relationship between teachers' beliefs and practices when implementing interactive computer models. (Contains 56 references.) (Author/WRM)

Using Computer Visualization Models in High School Chemistry: The Role of Teacher Beliefs

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Abstract

This paper discusses the role of high school chemistry teachers' beliefs in implementing computer visualization software to teach atomic and molecular structure from a quantum mechanical perspective. The informants in this study were four high school chemistry teachers with comparable academic and professional backgrounds. These teachers received training on the use of software applications and the underlying scientific concepts, expressed commitment to using the software with their classes, and taught students at the same academic level. All of the participants used the software to teach concepts related to atomic and molecular structure. Their instructional approaches ranged from superficial fact-based activities to in-depth student investigations and presentations. Evidence suggested that teachers' beliefs and personal goals shaped their decisions on how to use the software. Beliefs related to teachers' views about how students learn and their own roles as teachers had the greatest influence on pedagogical decisions. This paper describes the instructional strategies and the implied and stated rationales of participating teachers and develops a theory of a relationship between teachers' beliefs and practices when implementing interactive computer models.

Models used to describe atoms and explain their behavior have evolved over hundreds of years, with the most dramatic revisions being made a century ago. At that time, evidence of the quantized behavior of electrons led to mathematical models of atoms that had no analogues in the macroscopic world. The quantum mechanical model has been the scientifically accepted explanation for atomic and molecular behavior for the past hundred years.

Because electron configurations determine the properties of elements and compounds, the quantum mechanical model is necessary for comprehensive understanding of such factors as chemical bonding, molecular polarity, and solubility. Despite the importance of the quantum mechanical model, teaching concepts based on this model at the secondary school level presents challenges. Most high school students lack the mathematical skills required to perform calculations that predict electron behavior. Furthermore, high school chemistry textbooks provide only superficial facts about the quantum mechanical model and fail to establish convincing arguments for its superiority to other atomic models in predicting and explaining atomic behavior (Records, 1982; Shiland, 1997). Records (1982) identifies atomic theory as a particularly difficult topic to teach because of the lack of "meaningful learning activities" (p. 307). Harrison and Treagust (1996) concur, stating: "Atomic theory depends more than any other topic in chemistry on a variety of models to explain particulate behavior" (p. 514). A century after being found inadequate for explaining many of the properties of atoms and molecules, high school students still adhere to an outdated planetary model (Fischler, 1999; Rebello & Zollman, 1999).

The National Science Education Standards (NSES) (National Research Council, 1996) call for inquiry learning rather than didactic teaching. For abstract concepts, particularly those involving sub-microscopic particles, few resources have been available for inquiry learning. Computer visualization models now present opportunities for students to explore such abstract concepts through the inquiry processes recommended by NSES.

This paper describes the role of teachers' beliefs and attitudes in creating a learning environment that allows students to investigate properties of atoms and molecules using a scientifically acceptable quantum mechanical model. The question addressed in this paper is: How do teachers' beliefs influence their decisions about implementing interactive computer visualization models to teach concepts related to atomic and molecular structure? This question is important because it identifies: (1) how new technologies can be used to teach topics that were previously considered too difficult for high school students and (2) potential barriers to the

acceptance of these new methods. In a more general sense, this question also investigates factors that mediate teachers' decisions about instructional strategies.

Description of the Software

Quantum Science Across Disciplines (QSAD) software and instructional materials were designed to address the barriers to teaching modern atomic theory at the secondary level. The QSAD project, developed under a grant from the National Science Foundation (REC-9554198), created computer simulations that provide interactive visual models for students to investigate the properties of atoms and molecules. In developing a suite of software applications, the goal of the QSAD team was to provide a medium that would encourage and facilitate understanding a quantum approach to the study of biology, chemistry, and physics. One of the developers described QSAD software as a "computer-based manipulative" (Horwitz & Christie, in press), meaning that the user determines its purpose. Teachers and their students can adapt the software to meet a variety of instructional goals, but the unstructured format also requires teachers to create a context for using the software. QSAD applications can function as virtual laboratories in which the user can conduct experiments by manipulating visual models of atoms and molecules. Although this software can be accessed over the Internet, for this study students used the programs locally.

Summer institutes for secondary science teachers were held at Boston University in 1997 and 1998. Eight teachers from the greater Boston area attended these institutes. Three teachers attended the first institute, which focused on designing software applications appropriate for high school students. A new cadre of five teachers attended the second year, which emphasized development of curriculum materials to accompany the software. Both of the QSAD summer institutes included background information about the design, interface, and navigation of the software. Institute participants received instruction on how to use the software and engaged in several discussions with the programmers and scientists who designed the software. The institute participants demonstrated deeper understanding of quantum science concepts as a result of their own use of QSAD software as an inquiry medium. We were uncertain how their experiences in the summer institutes would affect their existing beliefs and practices.

Teachers' beliefs and actions

Many studies have identified the influence of teachers' beliefs on their pedagogical decisions. Several of these studies explored the relationship between a teacher's beliefs about how students learn and the methods the teacher employs (Ball & Cohen, 1996; Cronin-Jones, 1991; Hewson, Kerby, & Cook, 1995; Lyons, Freitag, & Hewson, 1997; Munby, 1984; Stofflett, 1994; Tobin, Tippins, & Gallard, 1994). Other research indicates that cultural factors influence teachers' perceptions about the capabilities of their students and their decisions about instructional contexts (Anyon, 1981; Lanier & Little, 1986).

The beliefs and values of science teachers have a strong influence on their pedagogical decisions (Garnett & Tobin, 1989; Hewson, Kerby & Cook, 1995; Lyons, Freitag, & Hewson, 1997; Nespor,1987; Pajares, 1992; Roth & McGinn, 1998). Studies indicate that teachers' epistemological beliefs affect how they teach (Yerrick, Parke, & Nugent, 1996) or that teachers' stated objectives are not always consistent with their instructional practices (Lyons, Freitag, & Hewson, 1997). Tobin, Tippins, and Gallard (1994) contend that "teachers' knowledge of student learning is based mainly on the teachers' own style of learning" (p. 48).

Fullan (1991) points out, "The failure of educational change may be related just as much to the fact that any innovations and reforms were never implemented in practice (i.e., real change was never accomplished) as to the fact that social, political, and economic factors inhibit change within the educational system" (p. 15). Cuban (1990) identifies factors that historically have inhibited changes in teaching practices, including time, uncertainty of outcomes, and repercussions from colleagues. Miller and Olson (1994) found that teaching methods are likely to remain constant despite the introduction of a new instructional medium such as the computer.

Ajzen and Fishbein (1980) contend, "beliefs are the major determinant of any behavior" (p. 223), and Ajzen (1985) notes that decisions are made by weighing the advantages and disadvantages of carrying out any action. The conflict between the two is often resolved "in favor of the more routinized response" (p. 19). Confidence in the appropriateness of the intended behavior is also a factor in its ultimate outcome. When the person is more confident in the intended behavior, "changes produced by new information will often be insufficient to reverse the planned course of action" (p. 21). Ajzen (1985) also points to the attitudes and possible actions of others as factors that affect how people behave. He adds that people's actions are influenced by "beliefs about the likely consequences of success and failure, the perceived probabilities of success and failure, normative beliefs regarding important referents, and motivations to comply with these referents" (p. 36). Thus, a number of competing factors contribute to a teacher's initial belief system, and those beliefs are the major determinants of subsequent actions.

Components of the educational experience

Schwab (1975) identifies four "commonplaces" that have equal importance in creating educationally sound learning environments. These are: the subject matter, the learner, the milieu, and the teacher. Ball and Cohen (1996) reconfigure Schwab's four commonplaces in terms of five "intersecting domains" (p. 7), which teachers consider when designing and implementing curricula. The five domains are: (1) beliefs about students abilities, experiences, and preconceptions; (2) teachers' subject matter knowledge and beliefs about that knowledge; (3) pedagogical knowledge and beliefs; (4) the milieu of the classroom; and (5) the culture of the school and community.

Teachers' beliefs about how students learn, what should be taught, and the implied and explicit expectations of the educational environment all influence their perceptions of how they should teach. Various models describe views of how learning occurs, the nature of science as a subject matter, and the role of the teacher. For this study, beliefs related to the learning process come under the umbrella, *model of the learner*. Beliefs about the teaching process are treated as important features of the *model of the teacher*. Beliefs about the nature of science are categorized as *subject matter beliefs*.

Models of the learner. Educational theorists advise teachers to base their pedagogical decisions on the learner rather than on the subject matter (see for example, Dewey, 1900/1990; Schwab, 1978; Whitehead, 1929/1957). However, even when teachers follow this principle, their pedagogical methods are shaped by personal conceptions of how learning occurs. Kohlberg (1987) identifies three models of learning, which he calls "streams of educational ideology" (p. 46). These are: romanticism, cultural transmission, and progressivism. In the first model, "romantics hold that what comes from within the child is most important aspect of development" (p. 46). The cultural transmission model is rooted in behaviorist theories, which propose that learning occurs through stimulus-response patterns. Knowledge is imparted from one source and

received by another. Kohlberg identifies this model as the basis for American education. The final model of learning–progressivism–holds that "ideas are redefined and reorganized as their implications are played out in experience and as they are confronted by their opposites in argument and discourse" (p. 51). This model currently comes under the name constructivism. This study used the latter two models of learning – transmission and constructivism – to inform the data analysis.

Cuban (1984) explains the combination of factors that encouraged the transmission model at the end of the nineteenth century. These include: the socialization role and organization of schools; the sociology, psychology, and belief systems of teachers; and the failures of educational reform efforts. Teachers who subscribe to transmission models of learning use techniques similar to those of a century ago. Their methods include lecture, textbook reading, and drill and practice, followed by assessments in which students reproduce the information they extracted from theses sources. Tobin, Tippins, and Gallard (1994) contend that science teachers "respond to textbooks in a way that contribute[s] to a transmission model" (p. 62).

Appleton (1993) describes students' responses to such learning environments. "Many learners have developed alternative cognitive strategies. [They] wait for correct information to be provided–by a book, the teacher, or some other authority–and then rotely learn what has been provided" (p. 270). In such contexts, students have little input into what is taught (Yerrick et al., 1997) and social development as well as higher-order thinking skills may be neglected (Fullan, 1991). The National Research Council (1999) cautions educators to be wary of such models of learning, which may reinforce rather than correct misconceptions. "The fact that learners construct new understandings based on their current knowledge highlights some of the dangers in 'teaching by telling'" (p. 59).

The constructivist learning model advocates learning strategies that facilitate students' opportunities to confront and modify their misconceptions. Students must also have access to alternative conceptions to replace their original ideas (Posner et al., 1986). Construction of knowledge is facilitated through the use of models, analogies, and other representations of ideas. Using these illustrative techniques, teachers can create an environment in which misconceptions are challenged and acceptable explanations are available to replace them. Schwab (1962) argues that scientists no longer viewed scientific knowledge as stable truths to be discovered and verified but as "principles of enquiry—conceptual structures—which could be revised when necessary" (p. 11), and calls for a similar approach to science education. Schwab advocates methods of discussion, student questioning, and inquiry learning. "For the student this means relinquishment of habits of passivity, docile learning, and dependence on teacher and textbook, in favor of an active learning in which lecture and textbook are challenged" (p. 66).

Models of the teacher. Models of teaching are closely aligned with models of learning. Kennedy (1991) notes that people have different beliefs about the nature and purpose of teaching and that the models teachers subscribe to "represent valid and probably enduring differences of view about the nature and purpose of teaching" (p. 276). She explains that in all models, teachers must be knowledgeable about both the subject matter and their students, but that differences in particular models of teaching affect "how these two objects of teaching are assumed to constrain and define one another" (p. 276). This study utilizes Kennedy's five models of teaching: additive, process, conceptual change, learning community, and transformation.

The additive model is the most traditional model of teaching in which students' content knowledge acquisition is the teacher's main goal. This knowledge comes in the form of "facts, concepts, principles, or laws that have been gathered through decades or centuries of inquiry into

a subject" (Kennedy, 1991, p. 276). Kennedy describes the teachers' mission as "reduc[ing] the gap between what students know about a subject and what they could know" (p. 277, emphasis in the original) by adding new information to students' existing knowledge stores.

As its name implies, the process model of teaching focuses on the processes and procedures "employed by those who contribute to the development of the academic subject" (Kennedy, 1991, p. 277). These processes include the "methods of operating, strategies, rules of evidence, and forms of argument" (p. 277) that are the norms of the discipline. The teacher's goals, as in the additive model, are to decrease the differences between students and experts. But, in this case, the focus is on the gap in procedural rather than factual knowledge.

Kennedy's conceptual change model has the same characteristics as the model proposed earlier by Posner et al. (1986). The teachers task in this model is to identify how students' conceptions are different from those of experts in the field and create a learning environment that facilitates the accommodation and assimilation of new ideas to create new metal constructs that correspond to the accepted views of the discipline. Kennedy (1991) identifies the challenge to teachers in identifying students' alternative conceptions. "Teachers must somehow learn how students think about phenomenon" (p. 278).

Using the learning community model, teachers establish classroom norms and practices, which determine "the kind of scholarship that is valued or shunned, the kinds of findings that are considered important as opposed to routine, the kinds of issues that are considered worth pursuing, and how members of the group are expected to interact with each other" (Kennedy, 1991, p. 279). As an alternative form of this model, teachers may combine the norms of the students and the experts in the field. Kennedy identifies the key feature of this model in terms of the teacher's focus. "What is relevant about academic subjects are those norms that deviate most strongly from student norms, and what is relevant about student norms are those that deviate most strongly from subject matter norms" (pp. 279-280).

The teacher's primary goal in the transformation model is "to render academic content relevant and meaningful to diverse learners" (Kennedy, 1991, p. 280). Teachers who conform to this model often use metaphors and analogies that make the subject matter more relevant to their students. Kennedy summarizes the challenges inherent in this model of teaching:

> The transformational task itself is bi-directional. On one side, the teacher must transform academic content into something that is meaningful and relevant to diverse learners; but the teacher's success in this can be measured by the extent to which students are transformed into people with and active interest in these academic areas. (p. 281)

Subject matter beliefs. There are several theories about how scientific knowledge is acquired, synthesized, and utilized. These theories include empiricism, nativism, positivism, and constructivism. The empiricist view is that "all knowledge is derived from sensory experience" (Lawson, 1994, p. 132). Positivism is an outgrowth of empiricism and espouses the idea that accurate predictions about phenomena can be made based on observations and logical analysis of data (Duschl, 1994). Nativists believe in a priori knowledge and contend that "the source of all knowledge is from within" (Lawson, 1994, p. 132). The constructivist model proposes that both beliefs and knowledge are products of human construction and develop from the individual's own experiences (Dewey, 1900/1990; Piaget, 1970).

Science teachers' beliefs about the nature of science and how science knowledge is obtained influence their instructional styles and attitudes about learning science. Research on teachers' conceptions about the nature and content of science has revealed that science teachers hold many of the same misconceptions as their students (Abd-El-Khalik & BouJaoude, 1997; Hewson, Kerby, & Cook, 1995; Novak & Gowin, 1984; Yerrick et al., 1997). Benson (1989)

found that even when teachers have a contemporary view of the nature of science, their stated beliefs are not always consistent with their classroom practices. Tobin, Tippins, and Gallard (1994) point to the educational experiences of teachers in which "their beliefs have been shaped by thousands of hours spent in college classrooms internalizing objective models of science" (p. 62) as reinforcing a view of scientific knowledge as "truth." Because the educational experiences of many science teachers were primarily through didactic instruction, teachers tend to have a realist philosophy about science (LaPlante, 1997; Mellado, 1998; Tobin, Tippins, & Gallard, 1994). Some studies have found that when teachers participate in professional growth activities, they often engage in reconstruction of their own scientific knowledge and beliefs about the nature of that knowledge (Oja, 1991; Tobin, Tippins, & Gallard, 1994).

Design of the Study

This research used a multiple case study design to investigate and compare the use of QSAD software in different settings. The study comprises four cases that include variation in the teachers' beliefs and instructional environment. Variations in the cases included: schools from different socioeconomic groups, the degree of collaboration teachers had with colleagues in their departments, the amount of QSAD training, and teachers' existing instructional practices. The approach to this research was one of an exploratory case study (Yin, 1994), using constant comparative methods (Cresswell, 1998; Strauss & Corbin, 1998) in data analysis.

Participants and Settings. The informants in this study included one chemistry teacher from each of four Greater Boston communities. Some of the informants taught more than one level of high school chemistry, but this study focused only on their honors level classes. Table 1 contains demographic data for the four communities.

Table 1. Demographic Data for the Four Communities

Town	Population	Income[a]	Per pupil spending	Education[b]
Thomsonville	55,000	$45,600	$7400	93% high school 60% college
Bridgeton	58,000	$38,500	$6400	82% high school 24% college
Cary	100,000	$95,000	$8300	96% high school 61% college
Easthaven	83,000	$59,700	$5000	92% high school 52% college

[a] Median household income
[b] Level of education completed with percentage of population for each

Of the four informants in this study, three had participated to varying degrees in a QSAD summer institutes. The fourth informant had served as a teacher-consultant on the QSAD project from its inception, and was, therefore, more familiar than the other informants with the design and capabilities of the software. Because the training experiences of the other informants occurred at different phases in the development of the software and varied in duration, the difference in this variable was not considered to be problematic. Each of the four participants was a veteran chemistry teacher between the ages of 43 and 52, with similar academic and professional backgrounds. The variation in their backgrounds is illustrated in Table 2, which also

contains information about their QSAD software training. Pseudonyms have been used for all of the informants.

Table 2. Biographical Data for Teachers

Teacher	Bachelor's Degree	Master's Degree	Teaching experience (years)	QSAD training
Nancy	Chemistry and German Literature	Natural Sciences	18	1997 4 weeks
Elaine	Chemistry	Chemistry	26	1998 2 weeks
Mike	Chemistry	Computer Science	29	1998 4 weeks
Matt	Chemical Engineering	School Administration	25	1996-1999 consultant

Data Sources

Data were collected from a number of sources including classroom observations, semi-structured and informal interviews, background questionnaires, and the Views on Science-Technology-Society (VOSTS) instrument (Aikenhead, Ryan, & Fleming, 1989). The total observation period for each teacher ranged from three to four months. Classes were observed on a daily basis before, during, and after the units in which QSAD software was used. Preliminary interviews with teachers included questions related to the teachers' perceptions of their teaching styles, methods used to assess student comprehension, and abilities of their students. Interviews after use of the software focused on teachers' instructional decisions and the rationale for those decisions. Brief, informal interviews with teachers assisted in determining issues related to computer instruction and pedagogical decisions as well as the rationale or motivation for instructional acts.

Interview and observation data were analyzed to determine the correspondence of teachers' stated beliefs and objectives with their instructional practices. Physical artifacts such as tests, worksheets, and lab instructions provided additional information related to teachers' goals and expectations for students and their emphasis on quantum science concepts. Activities written by the QSAD staff were offered to teachers for use with the software. Participants had the option of using the materials as written, modifying them, or designing their own activities. Their choices about these materials provided additional data.

Classrooms are complex social environments, which resist and confound simple analyses or explanations. Focusing on a few aspects of a complex system requires that important but secondary variables be ignored. In examining the factors that may have affected the informants' decisions about how to use interactive computer models, we chose not to take into account such factors as the teachers' other professional activities. We also disregarded variability among students, presuming that the students would be comparable because they were all enrolled in honors classes. These restrictions and assumptions permitted a degree of focus to the study.

Another source of variation was the software itself. The design and content of the QSAD software evolved during this study. The interactive, graphical approach to investigating atoms and molecules remained the same, but successive versions of the program introduced improvements in the user interface, added new functionality, and allowed users more control in their investigations. Because each of the teachers used a different version of the program with

their students, we have not emphasized which of the software applications or which versions they used. The analysis of the data focused primarily on teachers' beliefs about the role of computer-based manipulatives and their pedagogical decisions about how to incorporate those materials in their classrooms.

Each of the informants was asked to read a preliminary report describing his or her case and participate in a final interview to discuss their perceptions of the reports. This process served to verify the trustworthiness of the analysis (Merriam, 1988; Yin, 1994). In one instance, the teacher (Mike) agreed with all aspects of the report. In two cases, teachers (Nancy and Matt) expressed perspectives that differed from the syntheses of the findings. Their views were incorporated in the final drafts of their cases. In the fourth case, the teacher (Elaine) refused to discuss the findings and terminated further communication.

Findings

The discussion of the findings and conclusions that follow arise from an analysis of how teachers' beliefs and knowledge influence their decisions about using QSAD software. We have attempted to define teachers' beliefs in terms of their models of the learner, the subject matter, and themselves as teachers as well as the influence of the educational milieu. These models emerged from the teachers' statements, their instructional practices, VOSTS responses, and the instructional products they generated. We will first describe the belief systems of each of the teachers and follow with descriptions of how they used QSAD software.

Nancy. Nancy's emphasis on textbooks and memorization as well as her instructional methods reflected a transmission model of the learner. Her approach to teaching was to require students to first obtain knowledge from their textbooks; then Nancy added to or clarified their understanding. Nancy referred to her interaction with students as "class discussions" rather than lecture because students' questions initiated the flow of information. Nancy responded to those questions with straightforward transmissions of facts and procedures, asking for students' input in providing information. Nancy taught science as a body of facts and believed that those facts must be learned before students go on to more advanced courses. In Nancy's model of learning, the students' task was to obtain and internalize information. Once they had obtained this foundation of knowledge, students could apply the information in problem-solving activities.

Nancy's model of teaching was congruent with Kennedy's (1991) additive model. Reducing the gap between what students knew and what they needed to know was her primary concern. Students' personal interests in science topics were secondary to her goal of dispensing the essential information of the discipline. Nancy encouraged students to investigate related science topics on their own time, but was unwilling to shift the instructional agenda to accommodate those interests, at least of the students had taken the SAT II in chemistry.

Some aspects of Nancy's teaching aligned with the learning community model (Kennedy, 1991). Nancy identified goals for establishing the norms and routines that she perceived as being the tools and methods of more advanced students or scientists. She wanted her students to develop and internalize study and reasoning skills, which would help them in all future academic pursuits. She explained that one of her goals is to train students in the laboratory techniques and skills they need for entry into the science community. As in the learning community model, Nancy made an effort to "nurture scientific values and habits of thought" (p. 279).

A clear picture of Nancy's beliefs about the nature of scientific knowledge did not emerge from this study. In some ways, Nancy's beliefs about the subject matter meshed with her teaching and learning models. Nancy expressed the expectation that the amount and type of

scientific knowledge people should aspire to depend on their stage in the scientific community. Students should aim for a lower balance in their knowledge accounts than individuals at higher levels of involvement in the scientific community. Her VOSTS responses and our interpretation of her instructional practices suggested that Nancy perceived science as a body of facts and skills, which could be identified, isolated, and quantified, and consequently represent the currency of the subject matter.

However, Nancy disagreed with this interpretation of her beliefs about scientific knowledge. She expressed the following view:

> Science is like an inquiry. Science is a way of going about, learning more about nature. You need some knowledge, basic scientific knowledge, but I would not say that science is a set of knowledge. More inquiry, an endeavor to learn, using the scientific method, critical thinking.

Despite her stated position, Nancy's pedagogical approaches encouraged students to use their critical thinking skills more to understand the "basic scientific knowledge" than in "learning more about nature." The disparity between Nancy's statements and her instructional methods may be attributed to her hierarchical views of both participants in the scientific endeavor and the kind of knowledge that is appropriate at each level. Alternatively, Nancy may have two models of scientific knowledge – one practical and one theoretical.

The ethos of Thomsonville and its high school apparently had a strong influence on Nancy's ability to implement her models of teacher, learner, and subject matter. Parental and administrative expectations that students perform well on standardized tests, such as SAT II, influenced Nancy's beliefs that she should teach in a manner that resulted in the greatest accumulation of chemistry facts. Nancy's colleagues, who also emphasized content coverage, strengthened her perception that the most efficient method for students to prepare for tests was to accumulate a body of facts. This school fit Anyon's (1981) description of a "middle-class school" in which "work is getting the right answer" (p. 77).

Time was an important factor in this context, and Nancy maximized her opportunities to dispense knowledge during class time. Her methods required that students extract information from their textbooks before she verified and consolidated that information in class. This process meant that Nancy did not have to spend time covering information that students already understood. Nancy's frequent mention of class time suggested that it was a precious commodity, and she avoided activities that did not produce sufficient "per minute learning."

Elaine. Elaine and her colleagues at Bridgeton High School had redesigned their chemistry program two years prior to this study with the goal of providing a student-centered learning environment based on a variety of learning station activities. At the beginning of each instructional unit, students received a "contract sheet," containing a list of required and optional activities and column for teachers to verify completion. Teachers provided whole class instruction on "teacher days," while most class periods were "work days" in which students completed the prescribed activities. This educational environment reflected the working-class community. Anyon (1981) describes the type of activities performed by people in this socioeconomic group. "A working-class job is often characterized by work that is routine and mechanical and that is a small, fragmented part of a larger process with which workers are not usually acquainted" (p. 70).

Elaine perceived that students' principal source of scientific knowledge and alternative conceptions came from previous science courses. Consistent with the transmission model of learning, Elaine's exchanges with students suggested that what students learned in previous classes was retained as it was taught and that students shared her understanding of concepts she

had explained to them. When asked about students' preconceptions, Elaine's response indicated that they were not a consideration in her teaching.

Learning was product-driven in Elaine's class. The purpose for learning particular content was to prepare for a test or quiz or to be able to do the night's homework. The procedure of earning a grade based on the number of completed activities on the contract sheet was analogous to the piecework system of paying factory workers according to the number of items they produced. All work products had the same worth, and completion of activities was emphasized more than the learning that may have occurred in the process. Students showed little interest in the subject matter, and Elaine acknowledged that some students were only concerned with receiving credit for completing tasks or knowing how to answer questions for tests.

Elaine strongest belief was that students had to be actively engaged in the learning process. She described herself as a facilitator, and described her role in that capacity as follows:

> I mean lecturing, to have them listen and to obey my every word. But to help them as they learn themselves. I mean, their learning is up to them. I'm here to help them, to explain where necessary. They have to do it on their own to really learn it.

Elaine facilitated students' learning primarily by providing the sources of information through which students could access chemistry facts and skills and by monitoring the results of their efforts.

Elaine's model of teaching was similar to Kennedy's (1991) additive model with a notable modification. Her goal was for students to decrease the gap between their content knowledge and the accumulated facts of the discipline, and she supplied the resource materials that could provide that information. As a teacher, Elaine was one of several potential sources that could add to students' existing knowledge, but students had the primary responsibility for identifying as well as obtaining the knowledge of the discipline.

Elaine's responses to the VOSTS questionnaire suggested that she viewed science as a body of knowledge, and her comments suggested that she believed this body of knowledge could be transmitted from a number of sources–teacher, textbook, video, or computer–directly to students' minds. Elaine's expectation that students would obtain information of similar quality from a variety of sources was further evidence of a belief in a transmission model of learning. The following comment exemplifies Elaine's point of view: "Hopefully there's enough repetition in the different things, that they'll at least be exposed to the major concepts. If they don't get it in the computer they'll get it in the video or whatever."

Mike. Mike's instructional strategies reflected a constructivist model of learning. He used his prior experiences with chemistry students and knowledge of the individual students in his current class to assess what prior knowledge students brought to their learning experiences. He then designed activities that would make use of students' preconceptions, experiences, and interests. Through demonstrations and laboratory exercises, Mike provided experiences designed to challenge students' weak or naïve conceptions. He also created opportunities for students to bring their personal perspectives into their study of chemistry and to experience the social and technological aspects of the discipline through class discussions, student presentations, projects, and use of computers and scientific instrumentation.

Mike's model of the teacher most closely resembled Kennedy's (1991) transformation model but also contained some aspects of the conceptual change model. Evidence of the transformation model was at the organizational level. Mike's emphasis on the social and emotional aspects of learning were evidenced in his leadership role in the development and implementation of cross-disciplinary curricula at his school and his inclusion of student presentations on topics of interest to them.

The conceptual change model was more apparent at the level of classroom instruction. Mike's objective was for students to investigate concepts and learn by guided discovery. He elicited students' current understanding and beliefs about concepts before providing experiences that might challenge those preconceptions. Once students had some degree of dissatisfaction with their previous ideas, Mike guided students' learning experiences to encourage the construction of more acceptable explanations for phenomena.

Mike's constructivist model of the learner mirrored his model of the teacher. He commented on the individual talents and abilities of his students and explained his goal of utilized each person's strengths in building his or her own knowledge. He also raised awareness of alternative approaches to learning and encouraged students to assist each other. Mike organized the learning environment and coordinated events so that students had opportunities to discover aspects of chemistry concepts before discussing those concepts in class. The students in Mike's class constructed their individual knowledge, but each student's construction influenced others in creating a conceptual community.

In Mike's classroom, the route by which students learned was varied and contained numerous branches and phases. Mike orchestrated the means by which students obtained information, but varied the sources. At times, learning began with the textbook or with Mike's introduction to a topic. On other occasions, in-class experiences, such as a demonstration, lab activity, or student presentation would be the starting point for the learning process. From there, students developed their understanding of concepts through a variety of paths. The possibilities included any combination of small group or whole class discussions, lab experiments, model-building, and computer activities. Mike created general lesson plans, but the nature and outcome of each day's activities determined how the next class began. For example, Mike accelerated his timetable for discussing periodic trends in atomic size and ionization energy because students' observations in the computer lab indicated that they had already discovered those trends.

Mike's beliefs included convictions about how scientific knowledge is acquired and how students learn. His comments about the epistemology of science made reference to students' expectations that the teacher should know everything and the inference that students have an empiricist view of scientific knowledge. Mike stated that in his view "science is a process by which we continue to build knowledge and that knowledge building process has bumps in the road and dead ends and keeps chugging along." This point of view was evidenced in Mike's instructional design. Students proceeded through a series of experiences that caused them to question their previous conceptions and rebuild their knowledge. However, Mike's instructional practices and his stated beliefs about the nature of science were incompatible with some of his VOSTS responses. For example, his choice of an answer identifying science as a body of knowledge stood in contrast to his classroom practices, which promoted inquiry and encouraged students to question information.

Mike also held beliefs about the capabilities of his students and the expectations of parents and the school administration. Although he was aware of different learning styles and a range of abilities in his students, his overall expectation was that his honors students were capable of the demands of a rigorous course. He also made several references to the standards set by the community and implied a motivation to meet the expectations of the school and parents that Cary students would perform well on standardized tests and be prepared for their academic work at college. Mike appeared to be influenced by the culture of the community and school, which encouraged students to take a questioning attitude. As with Anyon's (1981) example of an

"executive elite school," the expectation at Cary High School was that students would develop their "analytical intellectual powers" (p. 83). Mike's teaching methods reflected that goal.

Matt. Matt described himself as a constructivist, and many of his classroom practices reflected that approach to learning. He varied his instructional styles depending on the size and focus of the group, employing both cooperative and competitive strategies. In small group activities, Matt encouraged students' cooperation with team members. In larger group discussions, he prompted students to listen critically to their classmates' ideas and challenge those points with which they disagreed. Matt also offered criticisms and suggestions about their ideas and the manner in which they expressed their thoughts. Another variation in Matt's teaching methods involved the locus of control for learning. On some occasions, students determined the direction and focus of their inquiries, while at other times Matt dominated the class with long, detailed explications.

Students learned by multiple methods and used various combinations of those methods. Their initial source of information was the textbook, but the sequence through which students' knowledge and understanding grew varied from one day to the next. Students learned from each other and from Matt through small group and whole class discussions, lecture, laboratory activities, computer investigations, and demonstrations. Students reflected on their own ideas and created shared meanings with their classmates through the use of learning logs and concept maps. Many of Matt's instructional techniques led to identification of misconceptions, which often motivated students to re-explore their ideas.

Matt's model of teaching fit Kennedy's (1991) conceptual change model but also contained some aspects of the learning community model. As in the conceptual change model, Matt's goal was to identify students' preexisting notions about chemistry and transform their ideas into "concepts that are like the concepts formed by experts in the field" (p. 278). Kennedy also describes conceptual change teachers as using assessment methods that focus on students' thoughts and reasoning processes rather than production of acceptable answers. Matt's assessment methods included concept maps, learning logs, and student presentations.

Matt's model of the teacher was similar to the learning community model in his emphasis on developing habits and establishing norms of behavior. His expectations of students in terms of homework, lab reports, small group work, and class discussions were well established by the time classroom observations began. He expected his students to approach their learning as scientists, identifying their interests in a topic, designing inquiries around those interests, and engaging in discussions with him and their peers. The class operated efficiently because students had internalized these classroom norms. For example, Matt did not mention specific homework assignments. Nevertheless, students frequently asked questions about their homework, and they all appeared to have read the same sections and attempted the same questions in the textbook. Like Kennedy's (1991) learning community teacher, Matt's classroom "reflected a pattern of practice… that enabled students to engage in a process of collective sense making" (p. 282).

Matt's teaching was spontaneous and flexible in response to what was happening in his classes, but at times, there was an apparent incongruity between Matt's theoretical model of teaching and his instinctive approach to his practice. While Matt espoused constructivist ideology and frequently employed methods that supported that model of learning, he also played the central role in the class on many occasions. In some cases, what began as class discussions became monologues in which Matt asked and answered his own questions. Most of the examples and metaphors Matt used were of relevance to him, but not necessarily to the students.

On the other hand, students' prior experiences were important to Matt in terms of the alternative conceptions they may have generated. Because of his personal interest in students' misconceptions, Matt's model of the teacher had the characteristics of the conceptual change model. In all instructional activities, Matt probed for flaws in students' ideas. Once detected, he described the misconception and gave examples of similar erroneous ideas. He then proceeded to describe the specific flaws in the students' statements.

In his VOSTS responses, Matt indicated a belief that scientific knowledge is built through a series of logical steps. This view was supported by Matt's periodic reference to his course as a "rigorous spiral." He conscientiously revisited previous concepts, adding other dimensions to students' understanding. Matt's interview comments and classroom practices also verified his view that scientific theories are discovered rather than invented. Student discussions, lab exercises, and computer activities were geared toward discovery of scientifically accepted explanations of chemical phenomena. Matt's comments indicated that he perceived models as valuable in being able to "predict reality," also suggested a logical positivist view of science. However, Matt rejected this interpretation of his use of the term "reality," stating that he meant the "real model" of the atom, not a "reality of nature."

The culture of the school and community appeared to coincide with Matt's goals for students to be able to verbalize their knowledge. In Matt's descriptions of his students, he mentioned the kinds of academic conversations that occurred in their homes. He seemed to believe that parents assessed their children's knowledge from these conversations. Matt's efforts to encourage learning through language were well supported by the milieu. Matt's classes were most closely aligned with Anyon's (1981) description of an "affluent professional school" in which "students are continually asked to express and apply ideas and concepts. Work involves individual thought and expressiveness, expansion and illustration of ideas, and choice of appropriate method and materials" (p. 79).

Use of QSAD Software

Despite some variation in how the teachers used the software, their approaches conformed to their models of learning and teaching. The transmission/additive model teachers used the software primarily to add to students' knowledge or confirm what they had learned from other sources. The constructivist/conceptual change model teachers use the software as a virtual laboratory, which allowed students to discover and test ideas about atoms and molecules.

Nancy. Fitting QSAD software into her established routine presented some challenges for Nancy. She commented that her students would have difficulty with the interface of the programs and made frequent reference to time constraints. Nancy was unwilling to devote her own time to designing software lessons. Therefore, one of the researchers prepared instructional materials for students to use in two different computer investigations. Nancy's only preparation was to review and suggest modifications that would provide more explicit directions.

Nancy also expressed concern that learning about atoms and molecules through software investigations would require more class time than by her usual methods. She planned to use the software for two lessons to be held in the school's computer lab. One lesson was designed to guide students in discovering periodic trends in ionization energy. For the other lesson, students would conduct a two-part investigation of polarity and the relationship between bond length and bond strength in diatomic molecules.

Nancy's first deviation from her plan for the ionization energy activity was to instruct students to use the textbook to partially complete the worksheet for homework. They filled in

sections of the data table indicating the number of electrons in each suborbital for the elements they would be investigating. In lab, the students were supposed to produce images of atoms for the first 18 elements and record the energy of the highest occupied orbital. Finally, they would graph this data to show the trend in ionization energy, discovering the pattern from their computer investigation.

However, on the day before the scheduled computer lab activity, a student asked about a homework problem involving ionization energy. Nancy expanded on her answer and described the relationship between the number of valence electrons and the energy required to remove an electron. She also explained the "special stability" conferred on atoms with half filled sub-orbitals and sketched the ionization energy graph on the board. After the class, Nancy realized that she had taught the material that students were to have investigated using the software. Subsequently, Nancy demonstrated these concepts using the QSAD software while students completed the worksheet, confirming what they had already learned in class.

Nancy's students completed the second computer lab activity as planned. In one part of the activity, they used the software to create specified diatomic molecules and compared the shapes formed by the electron clouds around nonpolar, polar, and ionic molecules. In the second part of the activity, students adjusted the internuclear distance between pairs of atoms to find the minimum bond energy and recorded that bond energy and the corresponding bond length. They experienced a few navigation problems, and Nancy relied on one of the researchers to help students locate the appropriate windows and menus. As with the previous computer lab experience, Nancy expressed more pleasure with her students' abilities in using the software than in the opportunity for them to discover some properties of chemical bonds.

Elaine. Elaine's use of QSAD materials conformed to her models of teacher, learner, and subject matter. The instructional design of the Bridgeton chemistry program called for students to learn from computer software for one third of the class periods in any unit. The applications they used were either electronic textbooks or drill and practice exercises. The work-products that resulted from these computer activities consisted of brief answers that verified students' use of the software. The teachers asked for assistance in designing activities for the QSAD software, and specified the kind of structure needed for students to be able to use these computer applications. They were not interested in using the software as a medium for investigating atomic structure. Instead, they specified an activity that would prompt students to create images of atoms and identify the ground state energies of the electrons and shapes of the electron clouds.

Elaine thought that students would ask more questions about atomic structure after using the software and would be more curious about how the graphical images related to the concepts they were studying. Rather than encouraging questions based on that curiosity, Elaine planned to rely on students to ask questions about what they learned using the software. She stated, "if they care enough, they will ask." In practice, the only questions the students asked related to software navigation and whether they were required to complete the QSAD activities.

Mike. Mike had a detailed plan for using the software. He laid a foundation through lab investigations in which students determined Planck's constant experimentally. The lessons included experiences that were linked to students' prior knowledge of light and the Bohr model of the atom. Through experimental results, students discovered aspects of the planetary model that were not supported by empirical evidence. They predicted the wavelengths of the emission spectra of hydrogen and helium through their own calculations and discovered that their predictions were accurate for hydrogen but not for helium. Students subsequently built their own

spectroscopes and used them to investigate the bright line spectra produced by sources at home or in the community.

Mike incorporated QSAD software into the next stage of this instructional unit through a guided investigation of electronic structure of atoms. For this purpose, students used the QSAD application in which the user selects the energy and sublevel of a single atomic orbital. The program generates representations of electron orbitals or densities of pseudoatoms. Mike had prepared a handout providing general guidelines and suggestions, but students' computer investigations varied. The instructions provided students with some technical guidance as they became familiar with the user interface, but the activities were also open-ended in that they allowed students to control variables and proceed through the investigations by different routes. Mike's rationale for using this particular application was to provide students with opportunities to understand the general properties of electron densities independent of particular atoms. The students asked many questions in the computer lab, but did not appear to be confused or frustrated by the software or in working with the abstract concepts of quantum science.

Mike also used QSAD software applications to guide students in the discovery of atomic structure and periodic trends in atomic size, ionization energy, and electronegativity. He was enthusiastic about the students' interaction and learning outcomes with the software.

> In periodic trends…especially ionization energy, QSAD was great at showing atomic orbitals, shapes, and I was able to see how students responded to the software that provided a visual base that they didn't have before. They had individual control of the software and had ownership. They didn't know the goal of using the software, but they were working toward the goal all the same. They found errors in the software, and that was good because it showed the kids this is a model, and like all models it has limitations.

Matt. Matt established a similar framework before students engaged in software investigations. His students first read about atomic structure in their books. Then they performed flame tests to determine the wavelengths of light emitted when various metal compounds were heated and conducted similar experiments using emission tubes. After students had collected their data in these labs, Matt began a discussion of different atomic models.

Students used the QSAD software for several investigations related to atomic structure and bonding. Before students' initial use of the software, Matt gave the following general guidelines for their investigations:

> Investigate something from the s area that actually has valence electrons in the s area, but at the light end of the atomic mass elements, and something on the p end, something that has a valence shell that's filled with p's. Learn what you can about both… I want you to learn how to use the controls and how to view all the different things, move in and out, flip axis so you can see different slices, learning where the nodes are and what have you, but concentrate on picking one of those two. That's what you'll do your report on.

Students followed these directions, learning how to navigate within the software and interpret the visual images as they investigated their choice of atoms. Matt circulated among the groups, answering students' questions, but primarily observing their use of the software. One half of the class worked in groups of three at computers while the remaining groups of students worked at their desks, discussing their plans for an investigation, constructing concept maps, or writing learning log entries.

Matt explained his rationale for this approach. He believed that his students were capable of reading and interpreting information from the graphical interface, such as relative energy of electron orbitals, occupancy, and differences in density views from different spatial orientations. He explained, "If they've got a particular task and they play around with the controls a little bit, they start to zero in on what's relevant." Matt realized that students had some trouble with the

interface, and he had a simple description of his strategy for those occasions. "They asked; I showed them." After students had investigated their atoms using the software, they prepared presentations, which included information about the visual displays. Through Matt's encouragement, other students asked questions and challenged the assertions of their peers, leading to spirited discussions about properties of atoms and molecules.

Conclusions

The intended use of QSAD software was for students to "have a greater opportunity to explore science and become acquainted with the process of science" (QSAD project summary). The software designers created unscripted applications to facilitate the use of the computer as an inquiry tool. In this format, students were unrestrained either in the images they could create or the sequence of their software investigations. Teachers were encouraged to use their own teaching experiences and knowledge of their particular students in determining the most appropriate use of the software in their classrooms. Although the software was designed for inquiry learning, results from this study show clearly that teachers' decisions about implementing the software were aligned with their models of teaching and learning.

When presented with new instructional materials in the form of QSAD software, the informants in this study were divided in their approaches. Nancy and Elaine, the transmission/ additive model teachers, used the software in a manner that conformed to their existing instructional modes. They relied on the QSAD team to develop activities but specified their preferred approaches as structured activities, whose aim was to deliver facts or confirm prior knowledge. The exception was Nancy's use of one activity in which students investigated the relationship between bond length and bond energy. However, in this case, after students collected the data, Nancy explained relationships to them rather than encouraging students to form and test their own hypotheses.

The constructivist/conceptual change teachers, Mike and Matt, also used the QSAD software in a manner similar to their use of other materials. These two teachers used the software for inquiry learning, which was guided by the teacher to greater or lesser degrees. In at least some aspects of their investigations, students devised their own techniques and focus for the investigations. They described the visual images they created, made comparisons based on changes in certain variables, developed hypotheses, and tested their ideas. Both Mike and Matt devised their own strategies for using QSAD software and adapted their original plans based on their students' responses.

The ethos of the schools both affected and was affected by the belief systems of teachers. Teachers who endorsed a transmission model worked in schools where their colleagues subscribed to the same model and where fact-based tests were used to provide evidence of students' learning. Nancy and Elaine both taught in schools where the milieu imposed shared models of teaching, learning, and scientific knowledge. The school culture of the constructivist teachers also influenced the degree to which they were able to apply their beliefs. Both Mike and Matt taught in schools where teachers were able to design and carry out their own curricula.

The combined models of learner and teacher were the primary factors that determined how QSAD software was used in the classroom. Other factors that appeared to support the use of inquiry methods included sufficient time for students to investigate phenomena, the amount of training using QSAD software, and the teacher's perception of either their students' abilities or the relative importance of the concepts to be learned using the software. Table 3 presents a

summary of the conclusions about the factors that affected teachers' use of the software. This table is arranged from greatest to least use of the software as medium for inquiry learning.

Table 3. Factors Affecting Software Use

Informant	Model of Learner	Model of Teacher	Class time (min/wk)	Perceived importance of concepts	Classroom interactions	Teacher autonomy	QSAD software training
Matt	C	CC/LC	315	High	Highly varied	High	High
Mike	C	Tf/CC	270	High	Highly varied	Mod-high	Mod-high
Nancy	T	A/LC	250	Low-mod	Little variation	Mod-low	Low-mod
Elaine	T	A	220	Low-mod	Little variation	Low	Moderate

Key:
C = Construction
T = Transmission
A = Additive Model
CC = Conceptual Change Model
LC = Learning Community Model
Tf = Transformation Model

Although the two more affluent towns, Cary and Easthaven, were the sites in which the QSAD software was used for inquiry learning, the socioeconomic status of the community did not appear to have a strong correlation to the teachers' use of QSAD materials. The neighboring towns of Easthaven and Thomsonville have similar socioeconomic compositions, but Matt and Nancy's models of teaching and learning were dramatically different as were their approaches to using the software. The two teachers' perceptions of community expectations were somewhat different in that Nancy perceived parents' expectations that instruction would emphasize preparation for standardized tests, while Matt believed that parents were more interested in their children's abilities to engage in intelligent discussions about what they had learned. These different beliefs contributed to the teachers' disparate choices about how to use the software.

Matt and Mike, the two teachers who used the software as an inquiry medium had several characteristics in common. Both demonstrated constructivist models of learning as well as complementary models of teaching. Conceptual change was an important theme for both of these teachers. Mike and Matt also employed a wide variety of instructional methods and sequences of learning activities. In both cases, the culture of the school allowed teachers the autonomy to use different methods in meeting their high expectations for student achievement. All of these characteristics were absent in the other two cases.

Comparisons of the two cases in which teachers used the software for transmission of information reveal both differences and similarities. Nancy had much higher expectations than Elaine with respect to her students' academic abilities and goals. The factors that these two cases had in common were the teachers' models of learner and teacher. Both teachers' classroom practices reflected transmission models of learning and additive models of teaching. Consistent with the combined transmission/additive model, the flow of information occurred in a linear fashion in both contexts. The belief that the goal of teaching is adding to students' information stores was supported by the milieu in both Thomsonville and Bridgeton.

The role of science teachers' views of the nature of scientific knowledge was inconclusive because classroom observations, teachers' comments, and VOSTS responses

provided contradictory data about how teachers perceived the nature of and process for acquiring scientific knowledge. In comparing the informants' views of science to the accepted positions of the scientific community, their interview responses were more aligned with those of scientists than were their classroom practices. The VOSTS instrument was not a good predictor of either teachers' stated beliefs or their pedagogical decisions.

Although time was not a focus of this study, it emerged as a consideration for some of the participants. The data show similar trends in the amount of instructional time and the degree to which teachers used the QSAD software as a tool for inquiry. Matt, the teacher with the greatest amount of class time per week, made greatest use of the software in an inquiry mode, while Elaine, the teacher with the least amount of time, made very little use of the software. However, a comparison of Nancy and Mike's situations shows a relatively minor difference in the lengths of their class periods but a major difference in their decisions about how to employ the software. The results of this small sample of teachers point to the possibility that longer class periods would increase the amount of inquiry learning.

This study identifies several factors that must be considered when attempting to institute educational reforms. Change is not a process that comes easily in classrooms or school systems. As others have found (Cronin-Jones, 1991; Nespor, 1987; Munby, 1982), teachers' beliefs influence their pedagogical decisions and should be considered when attempting to change classroom practices. For reform efforts to be successful, attempts at change must take into account teachers' belief systems and the prevailing ethos of the school system.

All four cases in this study revealed that the teachers acted as agents of the school culture. Reform efforts must address this aspect of the educational process. In schools that promoted development of critical thinking, questioning, and self-direction in students, teachers were more likely to use a variety of instructional methods and encourage construction of knowledge. On the other hand, schools that emphasized uniformity, control of student behavior, and "correct" answers fostered transmission of knowledge. The former types of schools offer the greatest potential for successful adoption of science education reform initiatives.

The link between school culture and teachers' models of learning and teaching may provide an approach for establishing policy changes that will be enacted at the classroom level. If teachers believe that the school and community value the development of critical thinking and student inquiry over test performance, they may be more inclined to use constructivist methods. On the other hand, if test scores are the method by which teachers and students are held accountable, teachers may be more inclined to use transmission methods.

At the level of the individual teacher, reformers who endorse inquiry methods will find allies in those teachers who employ constructivist models of learning and the complementary models of teaching. Based on this study, these teachers incorporate a variety of instructional methods and create learning environments that are more student-centered. Such pedagogical practices are aligned with the goals of inquiry learning as prescribed by the National Science Education Standards (NRC, 1996), indicating that the constructivist teachers support the goals of current science education reform.

Implications for future research

The results of this study leave unanswered questions about how teachers' beliefs influence their instructional decisions related to the use of computer models to teach atomic and molecular structure. Interactive computer models offer opportunities for teaching concepts that were previously considered too difficult for high school students. The results from this study

suggest that to understand why teachers embrace or reject new instructional approaches, we must identify how teachers' beliefs about teaching, learning, subject matter, and milieu influence their decisions. This information should then be used to investigate approaches for teachers to learn about and experience pedagogical approaches that foster construction of knowledge. These issues are of concern to teachers, teacher educators, curriculum developers, and school administrators. They also impact the success or failure of professional development initiatives and education reform.

The findings from this study suggest a close correlation between a teacher's model of the learner and his or her model of teaching. A broader study would provide data to support or refute this hypothesis and develop a generalized theory of teachers' models and could provide insight about how these models of teaching and learning develop or suggest methods for assisting teachers in revising their models to align with current learning theories.

The learning outcomes for students using inquiry-based interactive computer models should be investigated as well as the role of supporting materials in facilitating the use of inquiry-based learning. This study also suggests the need for an investigation into possible discrepancies between teachers' actual classroom practices and their stated beliefs about the nature of science or how science should be taught. Other areas of potential research include the relationship between teachers' models of the learner or teacher and the variety of instructional methods they use as well as the effect of teachers' beliefs and knowledge for systemic reform.

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